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The Whitfords Cusp— its geomorphology, stratigraphy and age structure

By V. Semeniuk[1] and D. J. Searle[2]

[1] 21 Glenmere Road, Warwick WA 6024

[2] 108 Dalkeith Road, Nedlands WA 6009
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Abstract

The Whitfords Cusp is a large triangular accretionary promontory situated at the southern end of the Whitfords-Lancelin sector of the inner Rottnest shelf coast. The subaerial portion of the accretionary cusp is composed of a diffuse dune terrain, the submarine portion of the cusp is a shallow (seagrass) bank structure, flanked by gently sloping margins that descend to deep water submarine depressions. The main body of the accretionary cusp abuts a rocky coastline cut into Pleistocene Limestone on the mainand. The cusp is developed leeward of a cluster of rocky prominences that comprise the Marmion Reef and Spearwood ridges.

The entire accretionary cusp is underlain by a Holocene sequence of Safety Bay Sand and/or Becher Sand. Radiocarbon analyses together with sealevel indications indicate that the cusp began accumulating *c.* 7860 C^{14} yrs BP with sealevel lower than present. Sealevel rose until it reached its present position and stabilised about 5000 C^{14} yrs BP. Reconstruction of isochrons (age structure) indicates that in the very late Holocene (i.e. *c.* 1300 C^{14} yrs BP to the present) the cusp has undergone a major erosional phase.

Introduction

The coastal environment of southwestern Australia encompassing the inner Rottnest Shelf is composed of Holocene accretionary sequences and limestone rocky shores. Recently Searle & Semeniuk (1985) described and classified this coastal environment and established five broad regional sectors each with its own geomorphology and style of sedimentation. Within this framework, Sector 4, the Whitfords-Lancelin Sector (Fig. 1), is composed of a shoreline mostly of limestone rocky shores with isolated intermittent large-scale accretionary cusps of Holocene sediment. Semeniuk & Johnson (1985) described limestone rocky shores that dominate this sector, but to date there have been no published details of the accretionary components of the Sector 4 system. Semeniuk & Johnson (1982) have described beach/dune sequences in the Safety Bay Sand previously in this area, and Semeniuk & Searle (1985a) have described the broad stratigraphy of the Whitfords area as a framework to a study of groundwater calcrete, but these works do not provide the detail of geomorphology, stratigraphy and age structure provided herein.

This paper presents information on the geomorphology, sedimentology, stratigraphy and age structure of the Whitfords Cusp, one of the best developed and largest accretionary cusps in the Whitfords-Lancelin Sector (Fig. 1), so that the area can serve as an example of Holocene accretion in this system. The term accretionary cusp is used in a macroscopic sense to refer to the large scale triangular sandy promontory in the area (see "cuspate foreland" in Bates & Jackson,1980). The term as used here is equivalent to "cuspate sandy foreland" of Bird (1976). The term should not be confused with small scale beach cusps that are developed periodically as a rhythmic feature along a shoreline.

The field methods used in this study included (Fig. 2): 1) mapping of sediment facies by ground traverses and diver traverses; 2) drilling by reverse circulation air core (10 sites); 3) augering by a vehicle mounted Gemco rig (4 sites); 4) pit examinations (10 sites); 5) airlift coring in underwater locations (7 sites); 6) levelling of sites relative to AHD and 7) collection of surface samples for laboratory analysis (47 sites). The laboratory methods included: 1) description of sediment in terms of fabric, texture, composition, colour; 2) aerial photograph interpretation, and 3) sorting of shells from air core material for radiocarbon analysis. The procedure followed in shell sorting is outlined in Searle & Woods (1986).

Regional setting

The Whitfords Cusp is a Holocene accretionary coastal deposit developed along the modern shoreline of the Swan Coastal Plain. As such it is one of a number of isolated Holocene accretionary cusps developed along the Whitfords-Lancelin Sector of the inner Rottnest Shelf coast. The nearshore and shoreline zone of this sector is characterised by a variety of features. The nearshore bathymetry to depths of 30 m is characterised by well defined largely submarine shore-parallel limestone rocky ridges, that may also form reefs and islands. These ridges from east to west are termed the Spearwood Ridge, the Marmion Reef Ridge and the

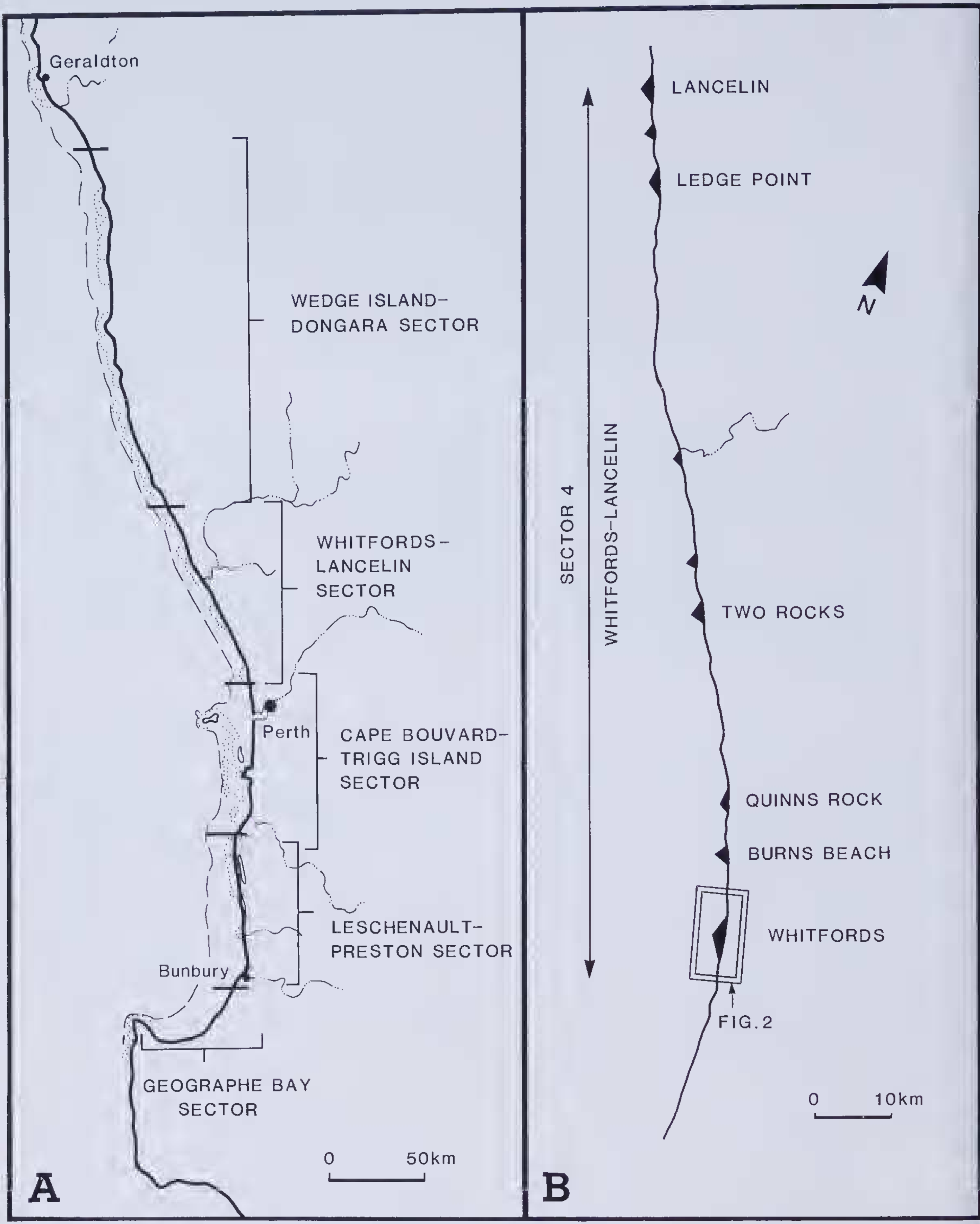

Figure 1.—A. Regional setting of the study area within the sectors of the Rottnest Shelf. B. The Whitford Cusp within the Whitford-Lancelin Sector.

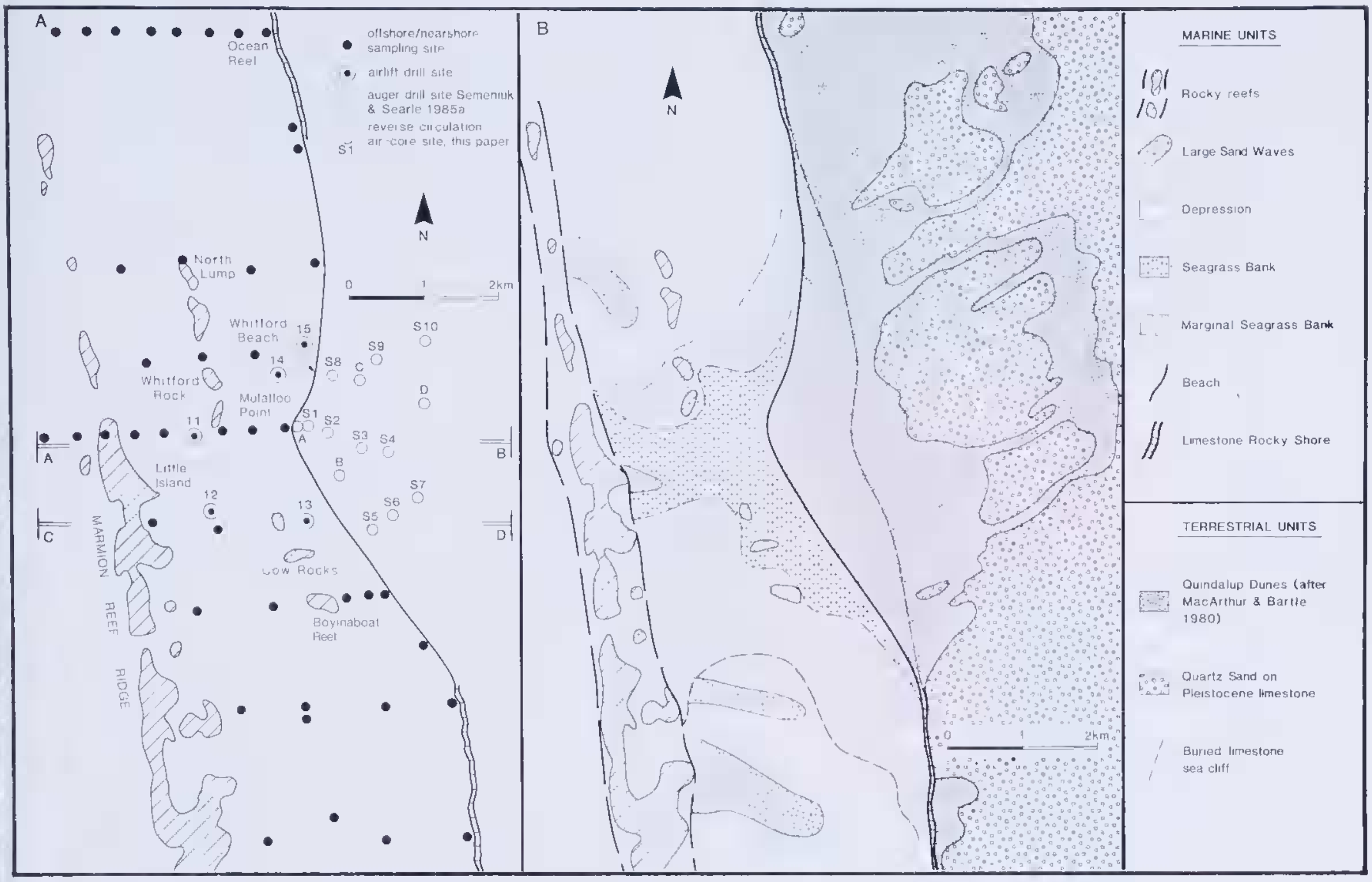

Figure 2.—A. Sampling sites and traverses used in this study. B. Facies distribution in the study area.

Staggie Reef Ridge (Searle & Semeniuk 1985). The coastline itself in this sector consists largely of a rocky limestone coast and pocket beaches with the discrete/isolated dune-topped promontories or accretionary cusps. The subaerial dune terrain of the accretionary cusp, comprised of fixed and mobile dunes, is referred to the Quindalup Dunes of MacArthur & Bettany (1960).

The oceanographic system along this portion of coast is typical of the regional pattern (Steedman & Craig 1983, Searle & Semeniuk 1985). The coastal zone is microtidal. In summer the prevailing wave regime is oceanic swell deriving from between west and southwest. This is supplemented by locally generated wind waves developed by seabreezes. The complex bathymetry of the nearshore marine enviroment dampens, refracts and diffracts the swell, as well as the locally-generated seas, developing complex convergences and divergences of wave orthogonals. This results in sediment transport and local sites of accumulation in loci of shelter i.e. the main Whitford Cusp. In winter, locally-generated wind waves are a significant influence supplementary to swell close inshore and during storms. Waves generated by storms approach mainly from northwest and west and are a major influence in sediment transport.

The Whitfords Cusp

The Whitfords Cusp system incorporates the area shown in Fig. 2B. Its natural boundaries are 1) the contact between Holocene sand and Pleistocene Tamala Limestone which defines the east margin; 2) the junction between Holocene sand and the limestone rocky shores to north and to south; and 3) the Marmion Reef Ridge which forms a sharp contact to west. Essentially the cusp is localised behind the island, reefs and rocky prominences around the Little Island group of the Marmion Reef Ridge.

Geomorphology

The Whitfords Cusp is composed of a subaerial triangular promontory, termed in this paper an accretionary cusp, and a submarine extension of this promontory into the marine environment as a subaqueous promontory or bank, which has been termed geographically Lal Bank. The subaerial portion of the cusp is composed of a diffuse dune terrain (Fig. 2B) wherein there are fixed steep parabolic dunes, fixed steep conical dune residuals, vegetated low dunes, mobile parabolic dunes and interdune depressions. MacArthur & Bartle (1980) have mapped various stages of dune development in this area. They subdivided the fixed and mobile dunes of the Whitfords Cusp into a time-related geomorphic-soil series of subunits termed Q1, Q2, Q3, Q4, with Q1, the oldest, and Q4 the youngest. Essentially all dunes are in various stages of vegetation and geomorphic degradation with moderate to thin soil cover. The dunes are aligned in a 80°-90° trend and indicate that much of the terrain is comprised of overlapping parabolic dune blowouts now largely fixed by vegetation.

The submarine promontory, that extends from Mullaloo Point of the Whitfords Cusp and its flanking beaches, to Little Island/the Marmion Reef ridge, is a shallow bank structure remarkably uniform in its depth

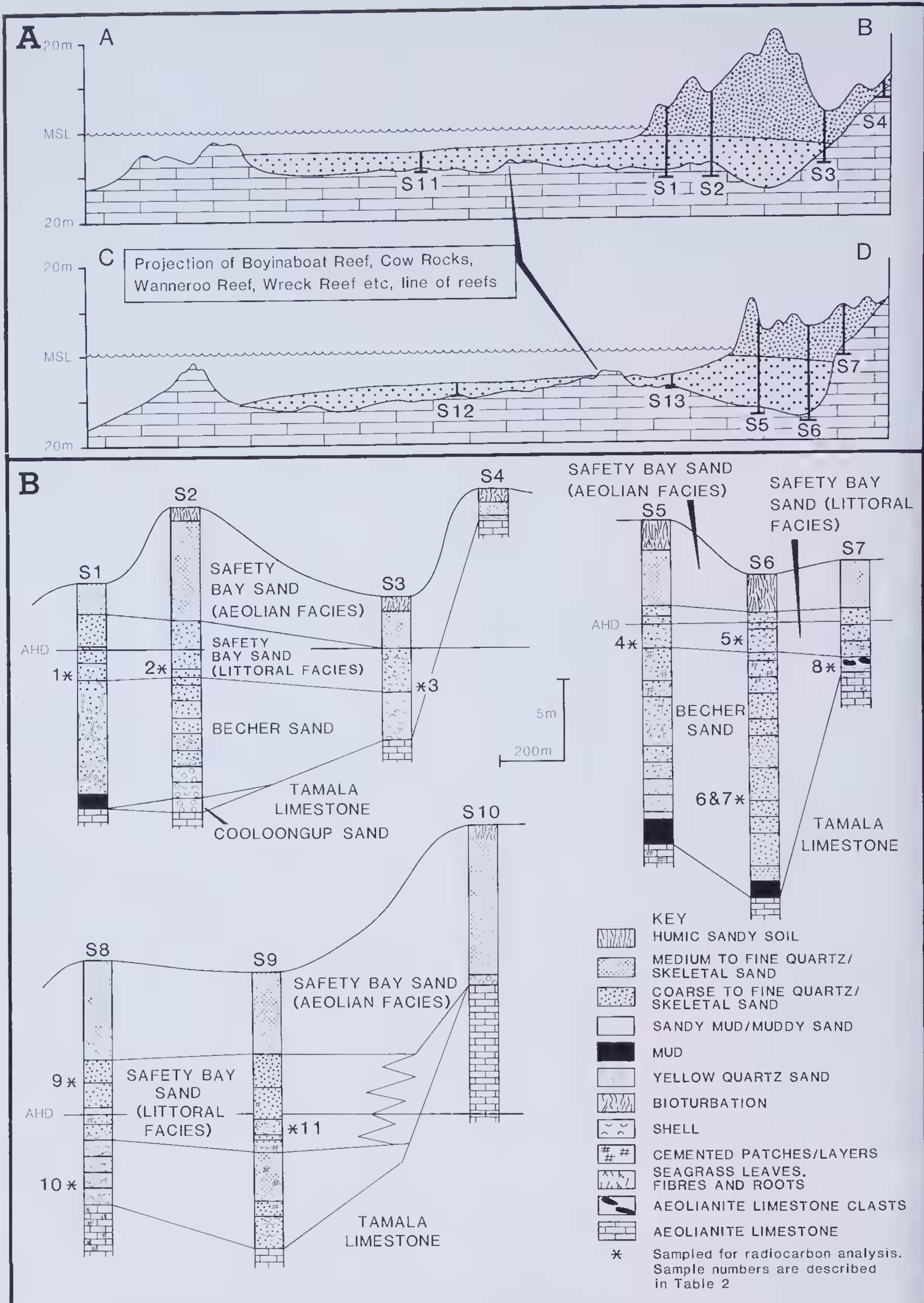

Figure 3.—A. Stratigraphic profiles across the Whitford Cusp. Location of cross sections are shown on Figure 2A. B. Detailed stratigraphic columns showing the onshore sequence.

along its crest-axis. The bank is some 4 km long, 1 km wide and 2-3 m deep. It descends on its north and south margins into submarine depressions some 8-10 m deep. The submarine promontory is largely seagrass vegetated, and in geologic terms would be termed a seagrass bank. The sloping margins of the bank are termed here marginal seagrass bank (Fig. 2B). Scattered through the shallow waters are limestone rocky reefs (e.g. Cow Rocks, Boyinaboat Reef, North Lump) that are part of the Spearwood Ridge. These rocky prominences however are mostly buried by Holocene sediments. Leeward of some reefs there are large scale sand waves 1-2 km long, up to 1 km wide and with 3-6 m relief and largely vegetation free.

The strip of shoreline separating the subaerial and submarine portion of the Whitfords Cusp is composed of beach, beachridges and foredunes wherein the geomorphic/sedimentary units of inshore, swash backshores and aeolian beachridge zones of Semeniuk & Johnson (1982) can be recognised. To north and south, the cusp is bounded by rocky shores cut into Pleistocene Tamala Limestone.

Sedimentary facies

The Holocene sedimentary facies of the Whitfords Cusp are relatively simple; they are (Table 1):

1) dune sand facies, 2) beach sand facies, 3) seagrass bank facies and marginal seagrass bank facies, 4) sand wave facies, 5) depression (or basin) facies, 6) rocky reef facies.

Each of the facies may contain several interrelated sediment types (Table 1). The distribution of these facies is shown in Fig. 2B.

Table 1

Description of Holocene Facies in Whitfords Cusp

Facies	Sediments	Description
Dune facies	dune sand	cross-layered to structureless to root-structured medium to fine, cream quartz skeletal sand
	soil	structureless to root structured to bioturbated humic, grey to brown quartz skeletal sand
	calcrete	occurs in very localised and isolated thin lenses only*
Beach facies	inshore	trough-layered to layered shelly, medium and coarse quartz skeletal sand
	swash	seaward-inclined, layered (shelly) sand; medium, coarse and fine quartz skeletal sand
	backshore	layered to disrupted (shelly) medium, coarse and fine quartz skeletal sand
	beachridge	cross-layered to structureless fine and medium quartz skeletal sand
Seagrass bank facies and marginal seagrass bank facies	sand and shelly sand	bioturbated to structureless to crudely layered (shelly) coarse medium and fine quartz skeletal sand
	muddy sand	bioturbated to structureless to crudely layered (shelly) coarse, medium and fine quartz skeletal sand with interstitial mud
Sand wave facies	sand	structureless to laminated fine and medium quartz skeletal sand
Depression facies	sand and shelly sand	medium and fine sand grading to coarse and medium skeletal quartz sand with shell gravel, grading to coarse quartz sand
Rocky reef facies	sand and shelly sand	apron and lenses of medium, coarse and fine quartz, skeletal lithoclast sand locally with shell and lithoclast gravel

* See Semeniuk & Searle 1985a

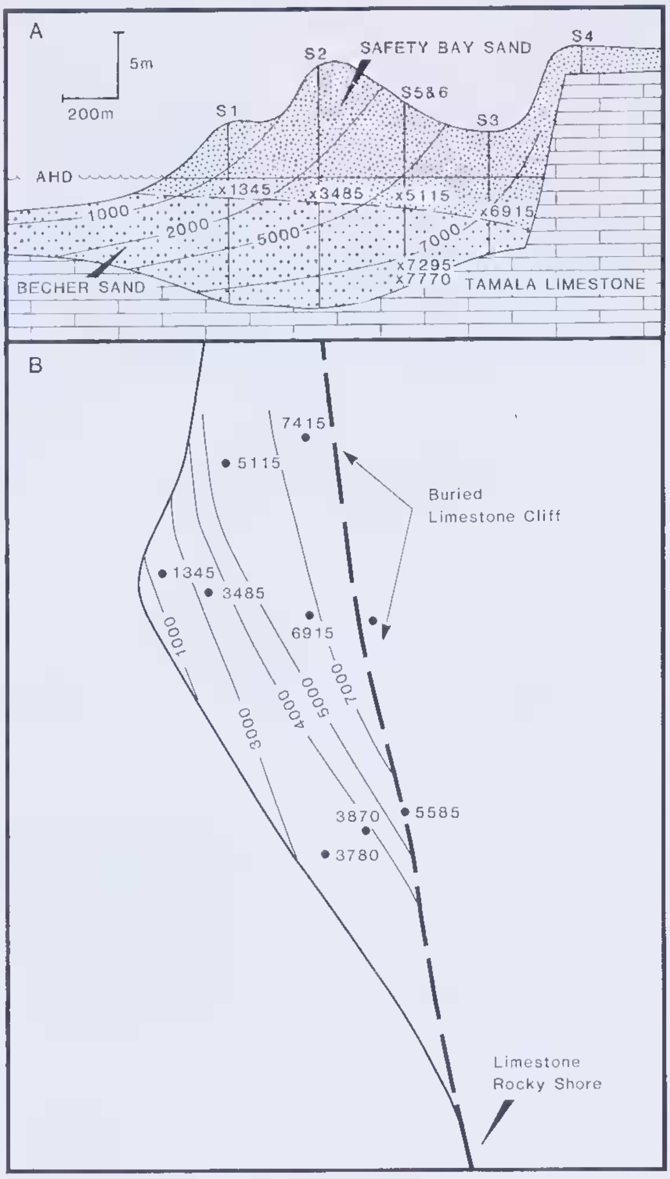

Figure 4.—Age structure of the Whitford Cusp as determined from radiocarbon results. A. Idealised cross-section incorporating litholgic and age data from geographically and stratigraphically complementary sites. B. Plan, showing isochrons (expressed as 1000 C^{14} yrs BP trending across cusp and truncated by modern shore. These isochrons essentially represent shorelines at the varying age intervals because shells from beach facies were used in the radiocarbon analysis.

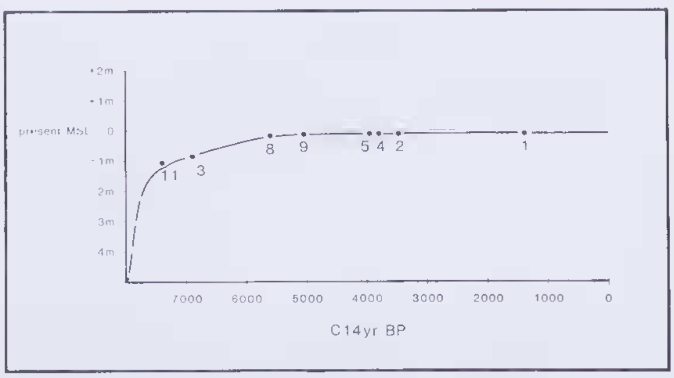

Figure 5.—Interpreted sealevel history of the Whitford area as determined by data of sealevel indicators and radiocarbon dates.

Stratigraphy

The main Quaternary formations in the area are:

- Safety Bay Sand (Passmore 1970, Semeniuk & Searle 1985b)
- Becher Sand (Semeniuk & Searle 1985b)
- Cooloongup Sand (Passmore 1970, Playford *et al.* 1976)
- Tamala Limestone (Playford *et al.* 1976)

In essence the stratigraphic sequence underlying the Whitfords Cusp is typical of the Becher Sand/Safety Bay Sand relationships described elsewhere by Searle (1984) and Semeniuk & Searle (1985b). Profiles showing the relationships between the formations are shown in Fig. 3. The Safety Bay Sand is composed of sediment of the dune and beach facies described above. The Becher Sand is composed of sediment of the seagrass bank facies. The Cooloongup Sand is a Pleistocene unit of yellow to orange quartz sand; the Tamala Limestone is a Pleistocene unit of aeolianite with marine intercalations.

Important features about the stratigraphic relationships are discussed below. The entire Whitfords Cusp and Lal Bank is underlain by a Holocene sequence of sediments that indicate shoaling: seagrass bank sediments are overlain onshore by beach sediments and in turn these are overlain by dune sediments (Fig. 3). The Holocene sequence rests on an unconformity cut into Pleistocene limestone, and along the eastern extremity of the Holocene deposits, the sequence is plastered on and abuts a buried rocky shore (cliff) cut into the limestone. Locally the Holocene sequence rests on Pleistocene Cooloongup Sand. Depressions in the limestone (e.g. the depression between the Spearwood Ridge and the mainland shore) are filled with and levelled by the Becher Sand.

The contact between Safety Bay Sand and Becher Sand represents a contact between beach and shoreface sediments and sublittoral seagrass sediments and as such it is a stratigraphic interface (=sealevel indicator 1) that may be used as a MSL indicator (Searle & Woods 1986). The modern contact between Safety Bay Sand and Becher Sand is approximately 1.5-1.7 m below present MSL corresponding to the modern interface between beach/shoreface and seagrass bank facies. However in older parts of the sequence the contact between Safety Bay and Becher formations is up to 2.7 m below present MSL. Use of the littoral facies (=sealevel indicator 2) within the Safety Bay Sand (p. 325 Semeniuk & Johnson 1982) provides similar results. The littoral facies of the Safety Bay Sand was deposited at and near MSL. An examination of the stratigraphic profiles in Fig. 3B indicates that for most of the sections the littoral facies accumulated at about present sealevel. In the older portions of the sections however the littoral facies occurs below the present position of MSL.

Age of sequence and age structure of cusp

Samples of shell and peat were collected from various intervals of the stratigraphic profiles (Fig. 3) and submitted for radiocarbon analysis for dating of the Holocene sequences. The materials used for radiocarbon analyses and the ages they returned are described in Table 2. The radiocarbon results are used here to: 1. confirm the Holocene age of the Whitfords Cusp (Fig. 4A), 2. determine the initiation and history of Holocene sedimentation in this area, 3. determine the rate of accretion of the stratigraphic sequence, 4. determine the age structure of the cusp and its relationship to modern geomorphology (Fig. 4B), and 5. determine the history of sealevel during the Holocene by dating the sealevel indicators.

The results from radiocarbon ages have confirmed that the sequence of Becher Sand and Safety Bay Sand are wholly Holocene (Tables 2 and 3). Age determinations from the shell and peat in deep portions of site S6, and shell from site S8, indicate that the post-glacial marine transgression had reached this shoreline by 7700-7860 C^{14} yrs BP, and that beach conditions were established at site S9 by 7415 C^{14} yrs BP. Ages returned from sites S6 and S8 indicate that the bulk of a seagrass bank can shoal from deep water facies to beach

Table 2

Description of material used for radiocarbon dating

Sample no.	Core site	Lab* no.	Depth	Formation	Type of material +	*Amount (g)*	*Why sampled* **	*Age C^{14} yrs with C^{13} correction*
1	S1	GX10637	6-7m	Safety Bay Sand	*Donax*	10	1	1345 ± 170
2	S2	GX10675	9-9.5m	Safety Bay Sand	Largely *Donax* (some *Brachidontes*)	24	1	3485 ± 150
3	S3	GX10638	5-6m	Safety Bay Sand	*Donax*	14	1	6915 ± 270
4	S5	GX10676	6-7.5m	Safety Bay Sand	*Donax*	14	1	3790 ± 145
5	S6	GX10677	3-4m	Safety Bay Sand	*Donax* + Glycymeris, *Brachidontes*	10	1	3870 ± 205
6	S6	GX10678	14-15m	Becher Sand	*Brachidontes*	7	2	7770 ± 275
7	S6	GX10679	14-15m	Becher Sand	Seagrass peat	5	3	7295 ± 130
8	S7	GX11101	5-6m	Gravelly shelly sand at unconformity	Mixed molluscs, mainly rocky shore assemblage	13	4	5585 ± 170
9	S8	GX10680	6.5-7.5m	Safety Bay Sand	*Donax*	20	1	5115 ± 165
10	S8	GX11100	17-18m	Becher Sand	Mixed gastropods *Thalotia*, *Phasianella* etc.	14	2	7860 ± 230
11	S9	GX11099	9-11m	Safety Bay Sand	*Donax* and mixed molluscs	5.5	1	7415 ± 360

* Laboratory No. for radiocarbon analysis Geochron Division, Krueger Enterprises Inc.

\+ XRD and thin section analyses from all these materials show no diagenetic alteration of shell

**1. to determine age of beach facies
2. to determine age of lower part of Becher Sand which in conjunction with age of beach facies provides data on rate of shoaling
3. supplementary material to complement and confirm age of shell from same horizon
4. age of shell deposit to date overlying beach facies

Table 3

Data on sealevel indicators

Site* No.	Sample No. used for radiometric dating	Age of indicator C^{14} yrs BP C^{14} corrected	Sealevel indicator 1		Sealevel indicator 2	
			Beach sand contact with Becher Sand	Position of sealevel at time of deposition	Littoral facies Safety Bay sand	Position of sealevel at time of deposition
S1	1	1345	Shelly coarse and medium sand overlying a sediment with a fine fraction	present level	Shelly coarse and medium sand	present level
S2	2	3485	Shelly coarse and medium sand overlying a sediment with a fine fraction	present level	Shelly coarse and medium sand	present level
S3	3	6915	Shelly coarse and medium sand overlying a sediment with a fine fraction	0.8m below present	Shelly coarse and medium sand	*c.* 1.0m below present
S5	4	3790	Shelly coarse and medium sand overlying a sediment with a fine fraction	present level	Shelly coarse and medium sand	present level
S6	5	3870	Shelly coarse and medium sand overlying a sediment with a fine fraction	present level	Shelly coarse and medium sand	present level
S7	8	5585	Not present	—	Shelly coarse and medium sand overlying gravel and shell on unconformity	*c.* present level
S8	9	5115	Shelly coarse and medium sand overlying a sediment with a fine fraction	present level	Shelly coarse and medium sand	present level
S9	11	7415	Shelly coarse and medium sand overlying a sediment with a fine fraction	1.0m below present level	Shelly coarse and medium sand	*c.* 1.0m below present

* see Table 2 and Fig. 3 for location and depths

facies in *c.* 2700-3900 C^{14} yrs (i.e. 7860-5115 and 7700-3870 respectively). A map showing ages of the shells from the beach facies at various sites indicates that the age structure of the Whitfords Cusp is internally consistent (Fig. 4B). However the interpreted isochron distributions are truncated by the modern shoreline, indicating that the cusp is in a major erosional phase.

The dating of sealevel indicators at the various sites enables a reconstruction of sealevel history for the interval of the Holocene *c.* 7860 C^{14} yrs BP to the present. (See Searle & Woods, 1986 and Semeniuk & Searle, 1986 for discussion of sealevel indicators in accretionary sequences.) The critical data pertaining to the two types of sealevel indicators, their ages and their stratigraphic level or position relative to present MSL are presented in Table 3. The stratigraphic profile in Fig. 3 clearly illustrates that earlier in the Holocene some sedimentary units were deposited with MSL slightly below present—for instance the Becher Sand/Safety Bay Sand contact at sites S3 and S9 is some 2-2.5 m below present MSL. On the other hand the same interface is 1.5-1.7 m below present MSL at sites S1, S2, S5, S6, and S8. The modern Becher Sand/Safety Bay Sand contact occurs as an interface 1.5-1.7m below present MSL. The littoral facies of the Safety Bay Sand shows a similar pattern. The facies occurs at about MSL for sites S1, S2, S5, S6, S7 and S8, but occurs below MSL at sites S3 and S9.

The evidence above indicates that there was deposition of sedimentary units earlier in the Holocene when sealevel stood *c.* 1 m below present. Age determinations of these units shows all sequences younger than *c.* 5000 C^{14} yrs BP as having formed with sealevel at about present position. Sequences older than 6900 C^{14} yrs BP were deposited with sealevel *c.* 1 m below present. The interpreted sealevel curve derived from the radiocarbon age data and levels of MSL indicators is shown in Fig. 5.

Developmental history of cusp

The post-glacial marine transgression reached the shore of the Whitfords area some 8000 C^{14} yrs BP. The initial stages of this marine incursion resulted in development of rocky shores as marine erosion incised into the Tamala Limestone terrain. Shore deposition began in this area *c.* 7415 C^{14} yrs BP with sealevel 1 m below present and steadily rising.

About 5000 C^{14} yrs BP sealevel had reached approximately its present position but by this stage a significant volume of the cusp had accumulated in the form of a seagrass bank capped by beach and dune sediments. The accumulation was developed behind the sheltered loci of the cluster of barrier islands, reefs and ridges of the Marmion Reef Ridge centred on Little Island. By *c.* 1300 C^{14} yrs BP the Whitford Cusp had accreted to its maximum width as preserved today. However in the very late Holocene the cusp has gone through a major erosional phase where the shoreline has retreated and incised into the Holocene deposits, markedly truncating the time planes (isochrons). The north side of the cusp has been cut back nearly to the 5000 C^{14} yr isochron; the south side has been cut back nearly to the 3780 C^{14} yr isochron; the tip of the cusp has been cut back to the 1345 C^{14} yr isochron. The respository of the eroded material is not known at present but it may either have moved out of the area as a shoreline ribbon, or it may have been lost into the adjoining depressions.

Discussion and conclusions

The Whitfords Cusp accretionary system is broadly similar to those described by Searle (1984) and Searle & Semeniuk (1985) in the Cape Bouvard-Trigg Is. sector of the Rottnest shelf in that the Holocene sequence consists of Becher Sand underlying Safety Bay Sand (Semeniuk & Searle 1985b). However the Whitfords Cusp differs from the Cape Bouvard-Trigg Sector cusps in a number of aspects.

Firstly the Whitfords Cusp is a relatively isolated accretionary cusp developed in the lee of an island/rocky reef area whereas the accretion in the Cape Bouvard-Trigg Sector locally has resulted in a series of adjoining cusps that have coalesced to form a broad prograded plain (e.g. Rockingham plain). Secondly, whereas the prograded plain at Rockingham still has clearly preserved surface beachridge trends (Fairbridge 1950, Seddon 1972, Woods & Searle 1983), the accretionary beachridge growth lines of the Whitfords Cusp have long been erased and overprinted by landward migrating parabolic dune blowouts. In the Rockingham Plain area the surface geomorphology (beachridges) trends were used by Woods & Searle 1983 and Searle & Woods 1986 to determine the history and age structure of the prograded plain, but in the Whitfords Cusp the age structure and growth trends (Fig. 4) can only be determined from subsurface information.

The extreme truncation of growth trends of the Whitfords Cusp by the modern shoreline (Fig. 4B) also contrasts with the history of accretionary cusps in the Cape Bouvard-Trigg coastal sector. These latter accretionary cusps generally are in geomorphic equilibrium with the growth lines/age structure and indicate that accretion is still proceeding. The Whitfords Cusp, however, has ceased prograding and is now in a major erosional phase.

The final aspect to emerge from the Whitfords Cusp area is the sealevel history as determined by sealevel indicators and the radiocarbon ages of selected stratigraphic intervals. Searle & Woods (1986) recently discussed the significance of the differences between sealevel curves determined from accretionary sequences as compared with those determined from rocky shores. The sealevel history curve determined from the Whitfords Cusp however not only is markedly different to curves derived from rocky shores in the region (Fairbridge 1961, Playford 1977) but it is also different from those derived from other accretionary shores such as Leschenault Peninsula (Semeniuk 1985) and Rockingham Plain (Searle & Woods 1986). This marked variation in sealevel history along a relatively short segment (170 km) of the Western Australia coastline is attributable to tectonic influences, a factor also raised by Playford (1977) to account for discrepancies between the sealevel history at Rottnest Island and Fairbridge (1961). The significance of the variable sealevel history along this coastline is discussed further in Semeniuk & Searle 1986.

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